FORECASTING RESEARCH DIVISION

Technical Report No. 61

Validation of Model Water Vapour using TOVS Satellite Sounding Data

by

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ABSTRACT

The accurate representation of water vapour is of increasing importance in GCM's. Observations are needed to evaluate the models. Radiosondes can be used, but are limited in their usefulness. Radiosonde observations of water vapour can contain serious errors, are spot values, and the coverage of many parts of the globe is poor. Data from satellite sounding instruments, though not without fault, are free of some of these difficulties. The TOVS (TIROS–N Operational Vertical Sounder) instrument on the NOAA polar–orbitting satellites provides global coverage at a resolution comparable to that of modern GCM's. Observed radiances can be processed to provide information on water vapour as well as temperature. In this paper, TOVS data are used to evaluate water vapour from a global model. Some mention is given of planned future satellite sounding instruments, and of their potential benefit to the validation of GCM results.

1 Introduction

The TOVS (TIROS–N Operational Vertical Sounder) instrument (*ref* Smith et al, 1979) is carried on the NOAA satellites (National Oceanic and Atmospheric Administration) – at present, NOAA–11 and NOAA–12. NESDIS (National Environmental Satellite Data Information Service, Washington) receive observations from the satellites, process them, and pass them on, at reduced resolution, over the GTS (Global Telecommunications System). The satellite observations are expressed as equivalent black body brightness temperatures at the frequencies observed by the TOVS instruments. At the UKMO, we receive these data and process them to obtain temperature and water vapour profiles at each observation location. The processing involves taking a NWP model background profile (actually a six–hour model forecast from the UKMO Unified Model, global, *ref* Cullen 1990) of T and RH, and using a radiative transfer model to simulate the brightness temperatures as would be observed by TOVS. We then compare the observed and simulated brightness temperatures and proceed iteratively to get a profile that combines model background and satellite observations in a statistically optimal way (*ref* Renshaw 1992). As a part of

that work, we monitor differences between the satellite observations (of brightness temperature) and those simulated from the model background. Some of those differences are examined in this paper.

2 The Satellite Data

TOVS comprises three instruments, only one of which, HIRS, is considered here. HIRS (High–resolution Infra–Red Sounder) has twenty channels, one of which is in the visible, and the rest in the infra–red. The HIRS footprint is approximately 40km in diameter at the earths surface. We receive up to 80,000 observations per day from the two–satellite system. NESDIS classify individual observations as to whether NESDIS consider them to be contaminated by cloud or not. In this paper only NESDIS clear fields of view are used. Figure 1 shows a typical days coverage of clear and cloudy spots, from both satellites.

3 What HIRS is Measuring

Figure 2 is a set of weighting functions for the TOVS instruments. The weighting function for a channel is an indication of the relative contribution to the measurement for that channel of temperature at each level in the atmosphere. It is dependent upon the opacity of the atmosphere at the frequency being observed. Most HIRS channels are at frequencies where the strongest absorbers are gases reasonably well–mixed in the atmosphere, such as CO_2. For these channels, the opacity does not change greatly, and the positions of the weighting functions are fairly well fixed. For channels looking at frequencies where water vapour is radiatively active, the opacity is dependent upon the water vapour in the atmosphere. The more water vapour, the more opaque the atmosphere, the higher peaks the weighting function, and so, generally, the colder the measured brightness temperature. Thus HIRS measures water vapour indirectly, by measuring temperature.

HIRS has four channels significantly affected by water vapour – channels 8, 10, 11 & 12. HIRS 8 & 10 are primarily window channels. HIRS–11 peaks, nominally, near 700hPa, and HIRS–12 near 500–hPa.

4 Comparison of Satellite and Model Brightness Temperatures

4.1 ...by chart

Figure 3 is a contour chart of HIRS–12, satellite – model, for one day. The differences at each observation point have been averaged onto $10^o \times 10^o$ latitude / longitude boxes for ease of viewing. By far the biggest differences occur between 30^o North and 30^o South. The differences tend to be positive over the Tropics, and negative over the Poles. The dipole at 45^o South, 110^o West, in the South–East Pacific, colocates with a strong depression. The large values at approximately 50^o East over Antarctica may well be due to model problems in this area. If we take the satellite observations, and the forward model, to be accurate to within a few degrees, then the range of values on the chart (10.3 to -3.7) can be ascribed to model error. The positive differences over the Tropics could be due to the model being either too cold or too moist.

Figure 4 is a chart for HIRS–11 on the same day, and shows similar features to HIRS–12, although with smaller values. Figure 5 is the same chart for HIRS–10. It can be seen that most of the signal here occurs over regions with extreme skin temperatures or orography – the Sahara, New Mexico, Greenland, the Himalayas and the Poles. Figure 6 shows HIRS–5. HIRS–12 and HIRS–5 have similar weighting functions, but HIRS–5 is not strongly affected by water vapour. The differences for HIRS–5 are an order of magnitude smaller than those for HIRS–12, and do not show the same Tropics–Poles pattern. Table 1 shows the sensitivity of each channel to temperature for different layers of the atmosphere. HIRS–12 is nowhere an order of magnitude more sensitive than HIRS–5.

We conclude that figure 3 is showing the model to be too moist over the Tropics, and possibly too dry over the Poles. This is in accord with a known problem of the model – an over–active Hadley circulation. It may be being driven by an excess of moisture, and so latent heat, in the model over the Tropics. Alternatively, the excess moisture may be a symptom of the problem.

4.2 ...by time–series

Figure 7 is a time series of globally–averaged satellite minus model brightness temperatures for NOAA–11, channels 5, 10, 11 and 12. On the 9th March, a change was made to the diffusion of humidity in the model. (Horizontal diffusion of specific humidity was changed from D2 to D4.) It can be seen that there was a significant impact on the mean differences for HIRS–11 & 12. The impact on HIRS–5 was small (– beware the different vertical scales). This change is confirmed by verification against radiosondes. Figure 8 shows mean and root–mean–square differences, model minus sonde. The excess moisture in the model has been reduced. This agrees with the change in satellite minus model brightness temperatures in the time series.

5 Future Instruments

The TOVS package is due to be replaced by ATOVS – Advanced TOVS – in mid–1996. ATOVS will retain HIRS, and will replace the current microwave instrument MSU (Microwave Sounding Unit) by AMSU – Advanced MSU – comprising AMSU–A and AMSU–B. AMSU–B will have five water vapour channels. Their weighting functions, for a typical tropical atmosphere, are shown in figure 9.

There are plans to fly more complex instruments towads the end of the century. These will be either spectrometers or interferometers, and may have several thousand channels. Figure 10 compares the TOVS moisture channels with just a selection of the moisture channels planned for HIS – High spectral resolution Interferometer Sounder (*ref* Smith 1991). It is estimated that these will allow the measurement of water vapour with 10% accuracy and 1km vertical resolution.

6 Conclusions

Satellite sounding instruments can play a useful complimentary rôle to radiosondes in the observation of water vapour. Radiosondes provide spot values. Sounding instruments give information at a horizontal resolution comparable to that of current operational forecast models. Radiosondes have limited global coverage and there are problems regarding

accuracy and standardisation. Satellite data provide good coverage, from one instrument.

Vertical resolution is poor for present sounding instruments. It is difficult to quantify differences in brightness temperature from the model as errors in , eg, model specific humidity. Despite these difficulties, satellite sounding data can be used profitably to evaluate model water vapour. Sounding imagery and large–area statistics are useful tools in this. Future potential is promising.

References

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Smith, WL, HM Woolf, CM Hayden, DQ Wark and LM McMillin 1979:
The TIROS-N Operational Vertical Sounder, GARP Topic no 58, 1177–1187 Bull. Am. Meteorol. Soc.

$$\frac{d\,(\text{Brightness Temperature})}{d\,(\text{Level Temperature})} \qquad \frac{(\text{Kelvin})}{(\text{Kelvin})}$$

as calculated from three representative profiles,

using forward model RTTOV, NOAA-11.

		polar				mid-latitude				tropical			
	HIRS channel:	5	10	11	12	5	10	11	12	5	10	11	12
T	10mb	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00
T	15mb	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00
T	20mb	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00
T	25mb	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00
T	30mb	0.02	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.02	0.00	0.00	0.00
T	50mb	0.03	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.02	0.00	0.00	0.00
T	70mb	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T	100mb	0.02	0.00	0.00	0.02	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.01
T	150mb	0.03	0.00	0.01	0.01	0.02	0.00	0.01	0.02	0.01	0.00	0.01	0.02
T	200mb	0.03	0.00	0.01	0.02	0.02	0.00	0.01	0.03	0.01	0.00	0.01	0.04
T	250mb	0.02	0.00	0.01	0.03	0.01	0.00	0.02	0.05	0.02	0.00	0.02	0.07
T	300mb	0.02	0.00	0.01	0.04	0.02	0.00	0.02	0.09	0.03	0.00	0.02	0.11
T	400mb	0.03	0.00	0.02	0.08	0.03	0.00	0.04	0.14	0.04	0.00	0.04	0.12
T	500mb	0.03	0.00	0.06	0.13	0.04	0.01	0.09	0.11	0.05	0.02	0.10	0.08
T	700mb	0.04	0.02	0.09	0.04	0.04	0.03	0.08	0.01	0.04	0.05	0.07	0.00
T	850mb	0.03	0.03	0.08	0.01	0.03	0.06	0.06	0.00	0.03	0.09	0.03	0.00
T	950mb	0.01	0.02	0.03	0.00	0.01	0.04	0.01	0.00	0.01	0.06	0.00	0.00
T	1000mb	0.01	0.02	0.02	0.00	0.01	0.03	0.01	0.00	0.01	0.05	0.00	0.00
T	skin	0.08	0.77	0.12	0.00	0.04	0.60	0.02	0.00	0.01	0.39	0.00	0.00

TABLE 1.

FIG. 1

ONE DAYS COVERAGE OF TOVS FROM NOAA-11 & 12
VIA NESDIS

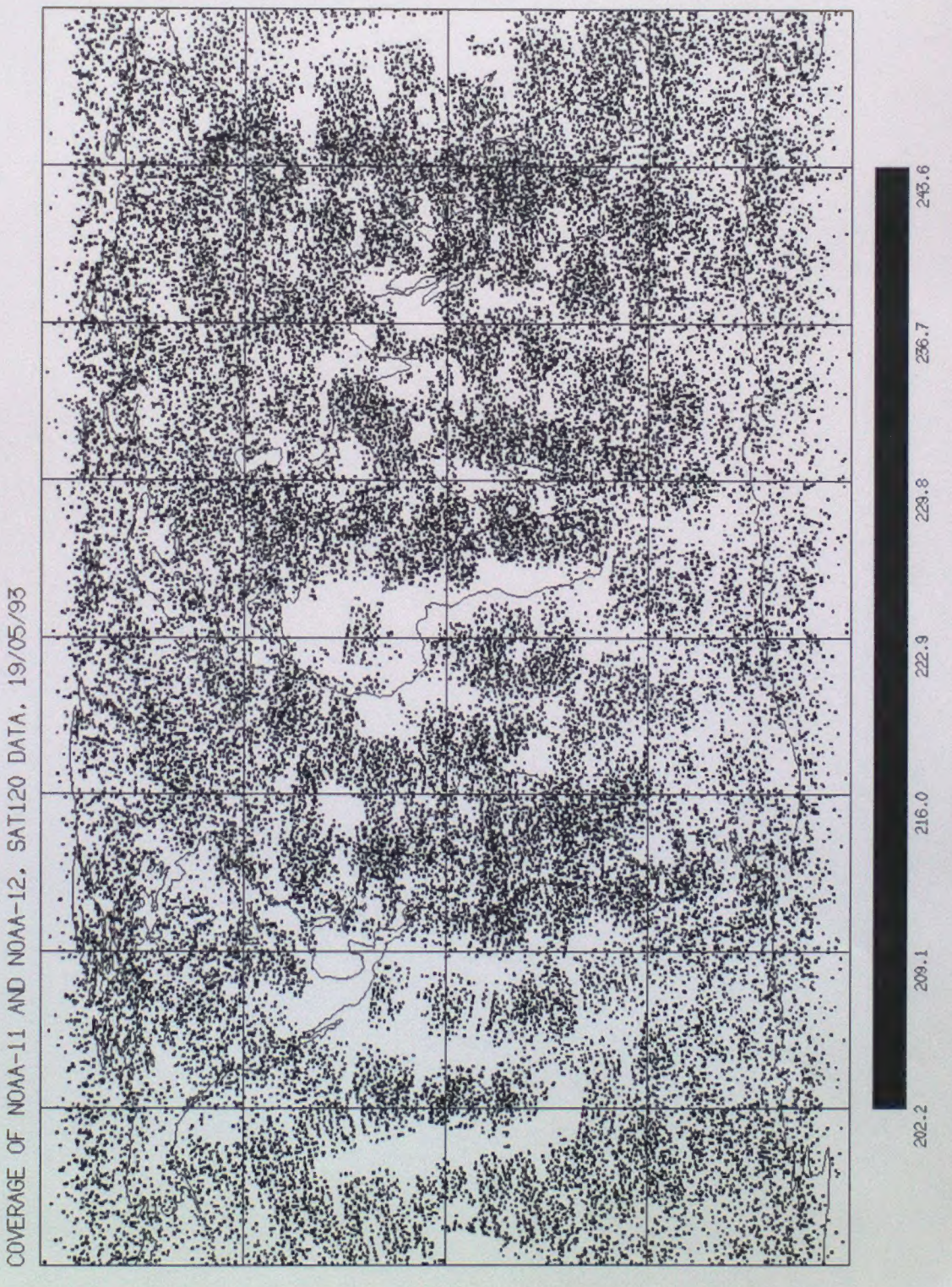
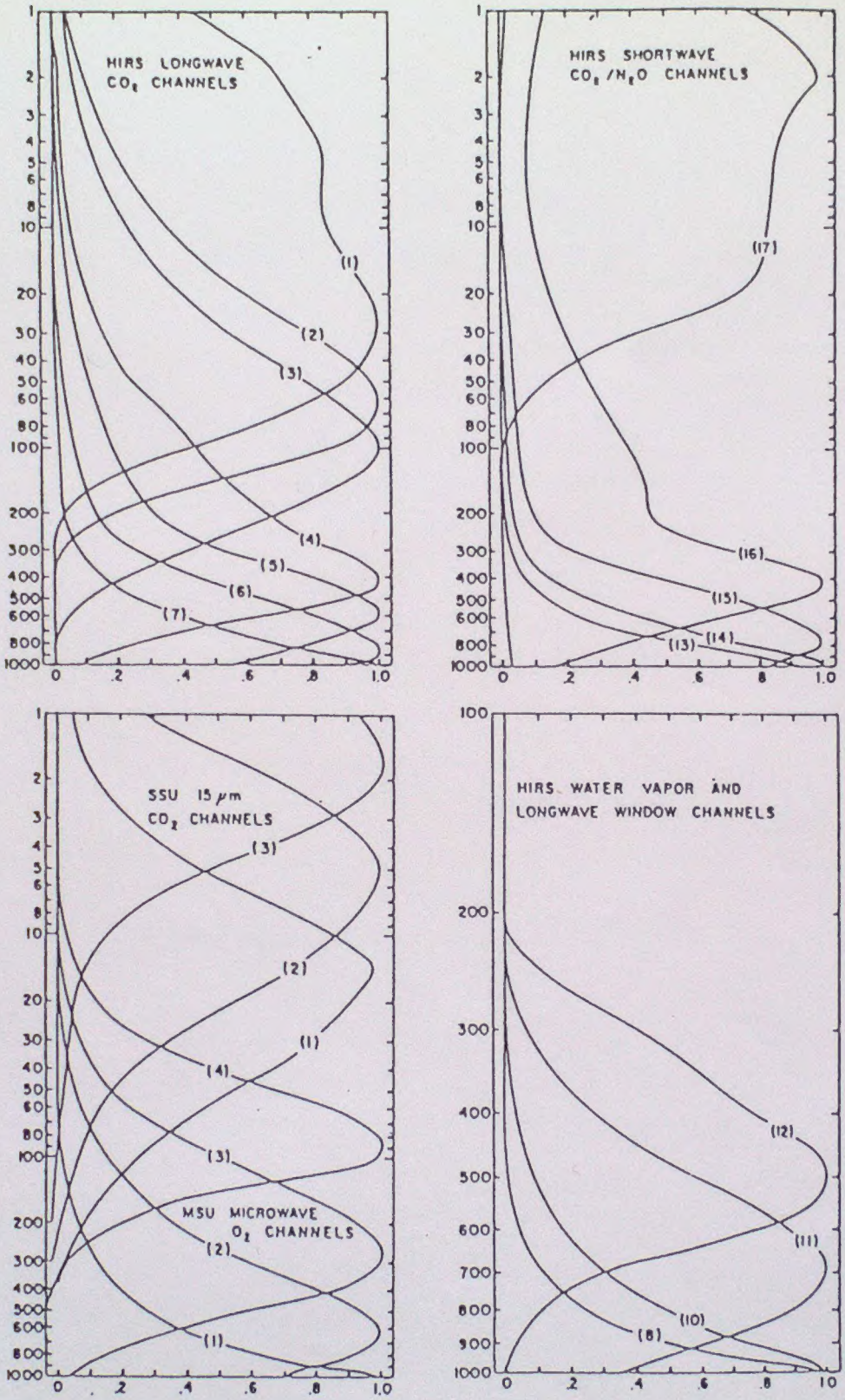


FIG. 2



TOVS weighting functions (normalized).

TAKEN FROM SMITH ET AL (1979)

FIG. 3

HIRS-12

OBSERVATIONS - MODEL

(BRIGHTNESS TEMPS IN KELVIN)

10° x 10° lat/lon boxes

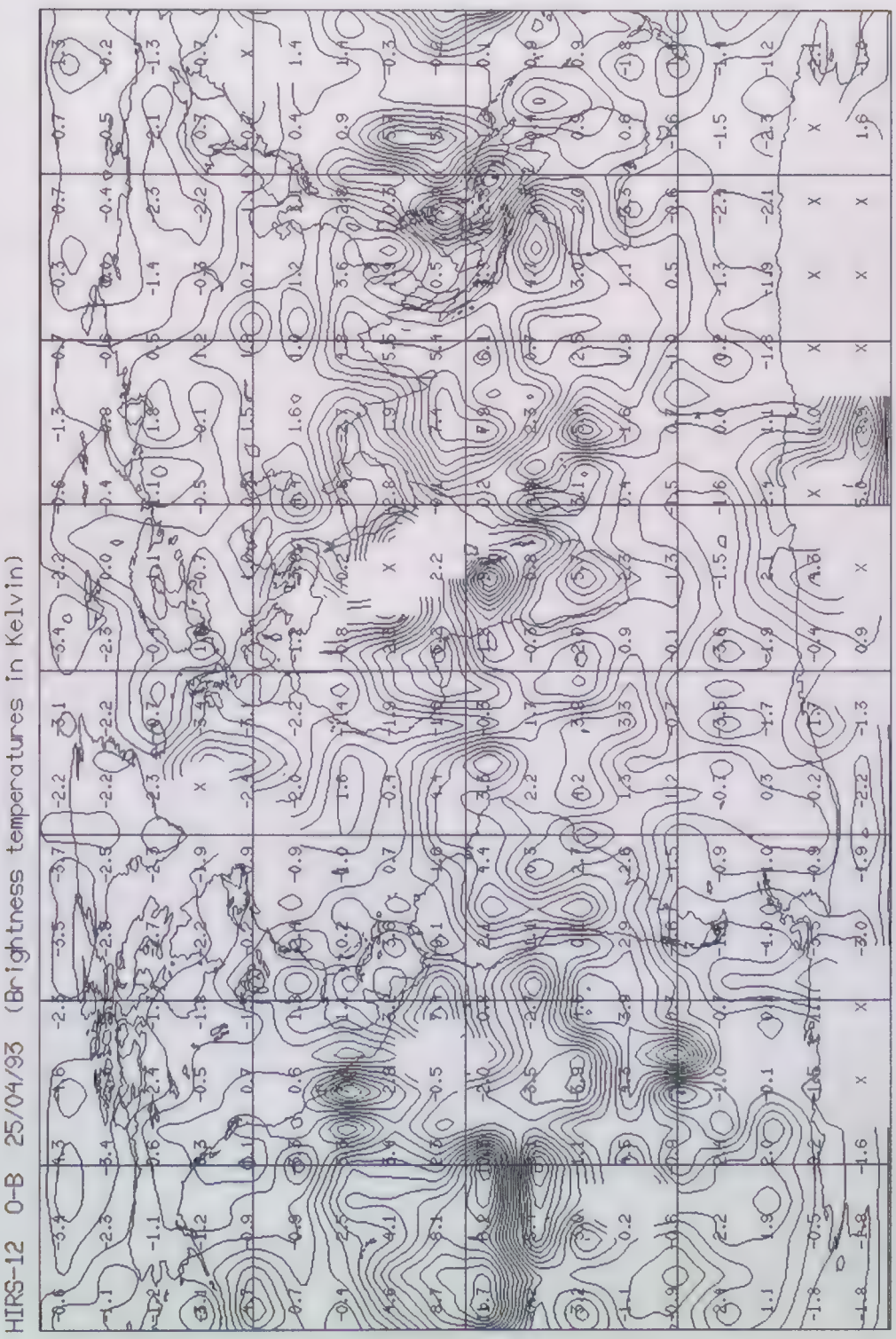


FIG. 4

HIRS - 11

OBSERVATIONS - MODEL

(BRIGHTNESS TEMPS IN KELVIN)

$10° \times 10°$ lat / lon boxes

FIG. 5

HIRS - 10

OBSERVATIONS - MODEL

(BRIGHTNESS TEMPS in KELVIN)

10° × 10° lat/lon boxes

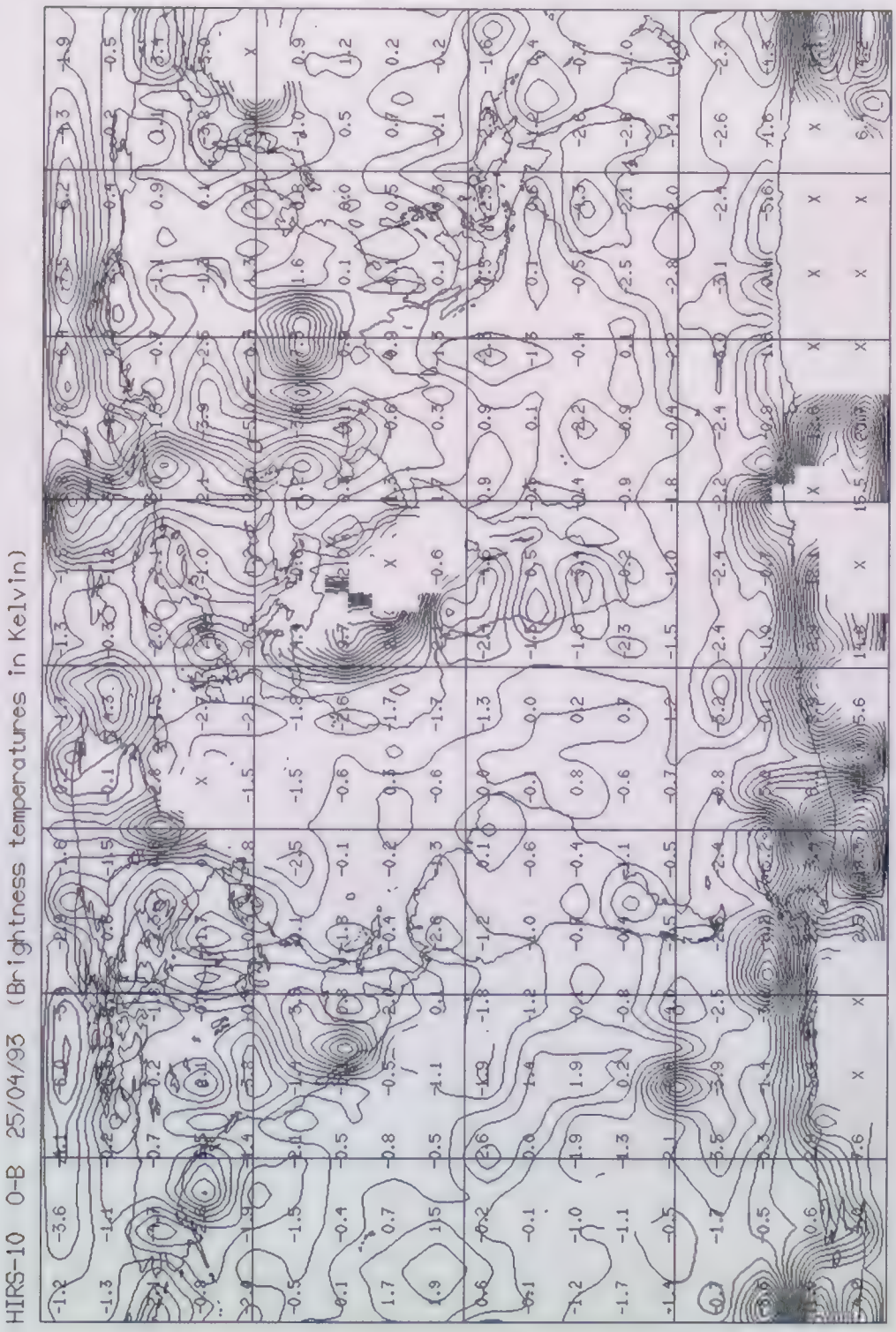


FIG. 6

HIRS-5

OBSERVATION – MODEL (BRIGHTNESS TEMPS, KELVIN)

25/04/93

10° × 10° lat/lon boxes

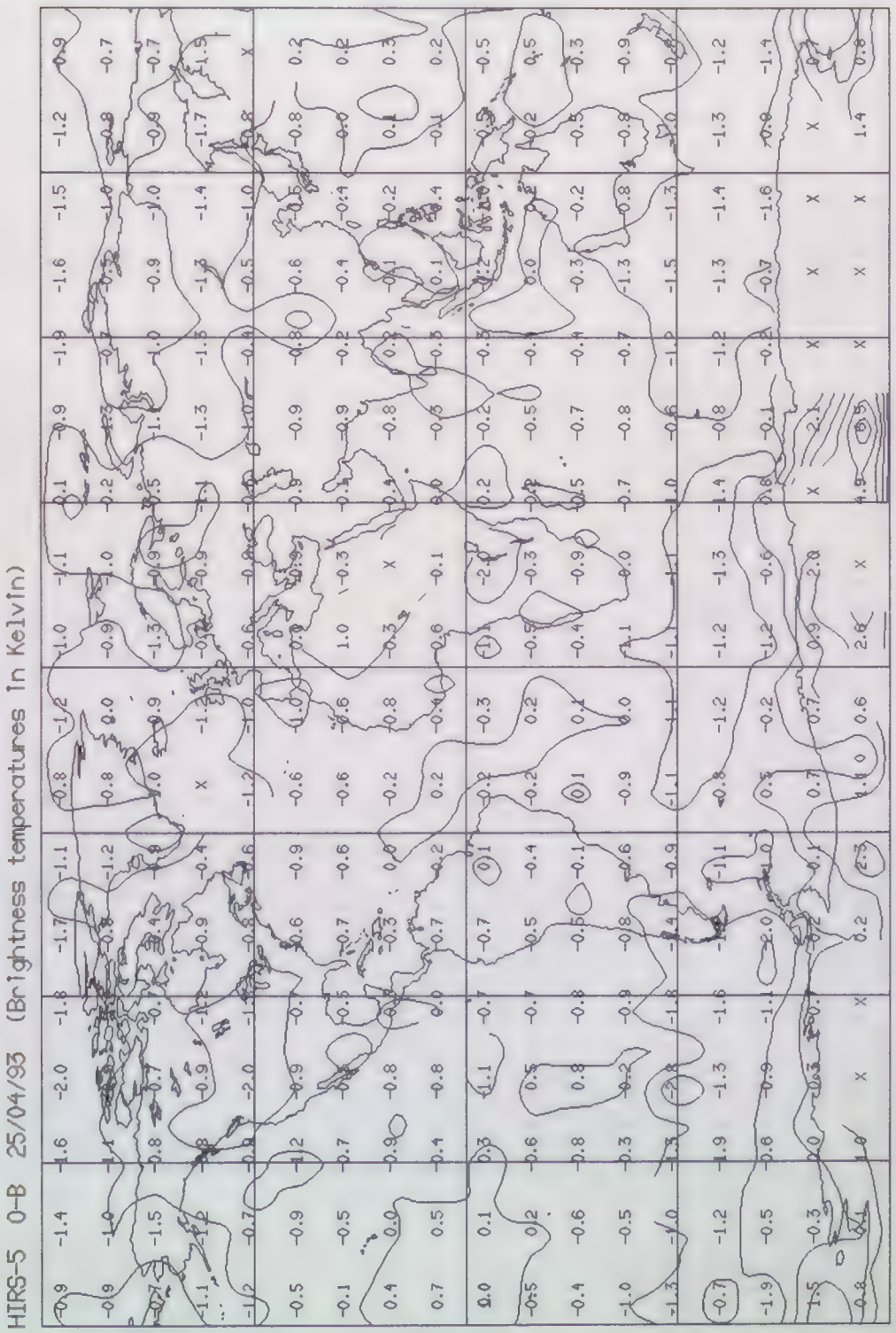
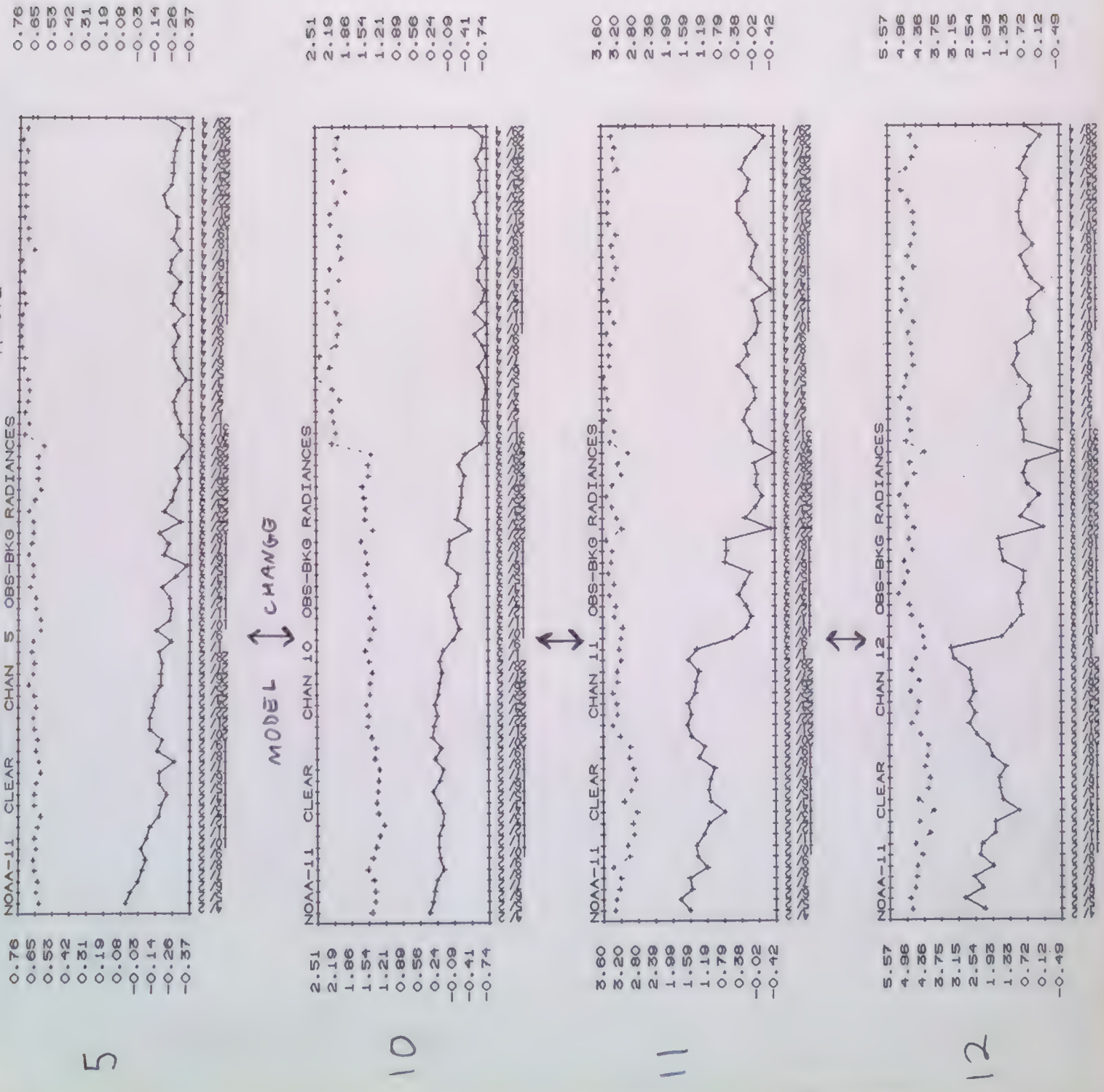


FIG. 7

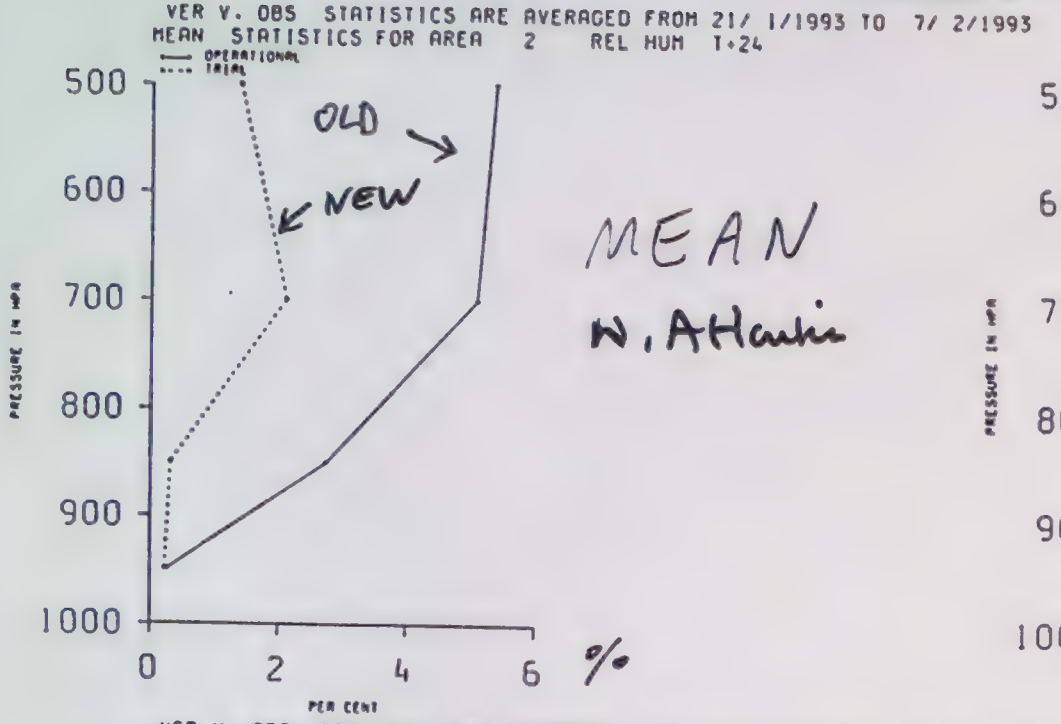
TIME SERIES: OBSERVATION - MODEL

(BRIGHTNESS TEMPS IN KELVIN)

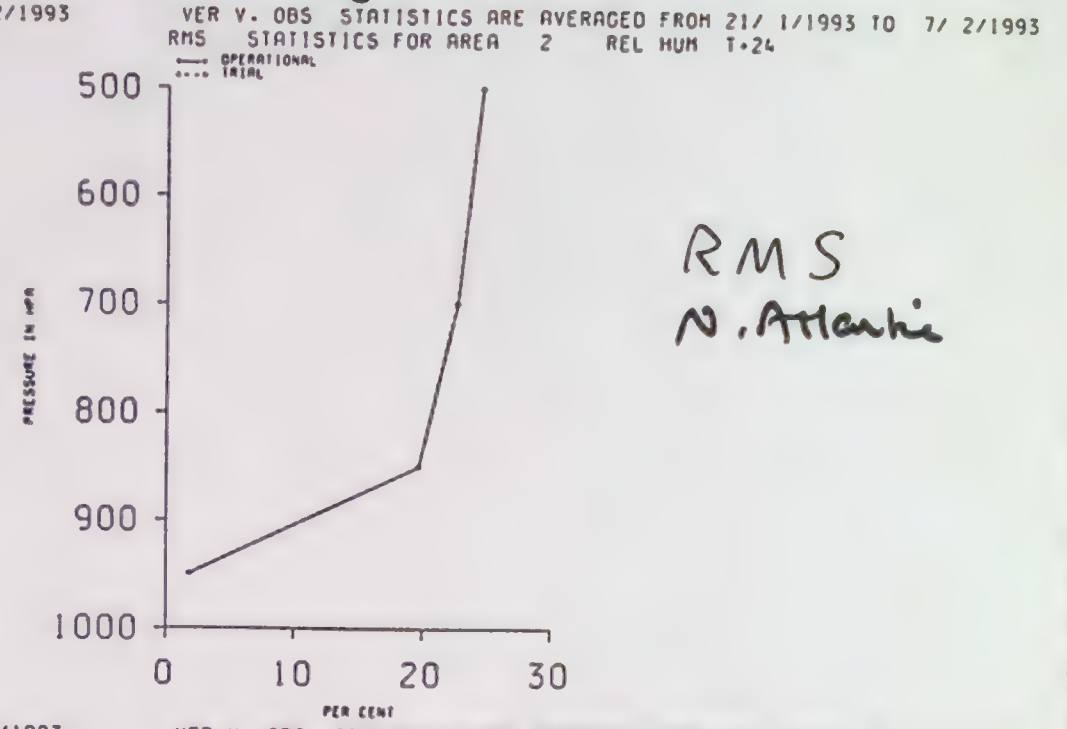
NOAA-11, GLOBAL AVERAGE



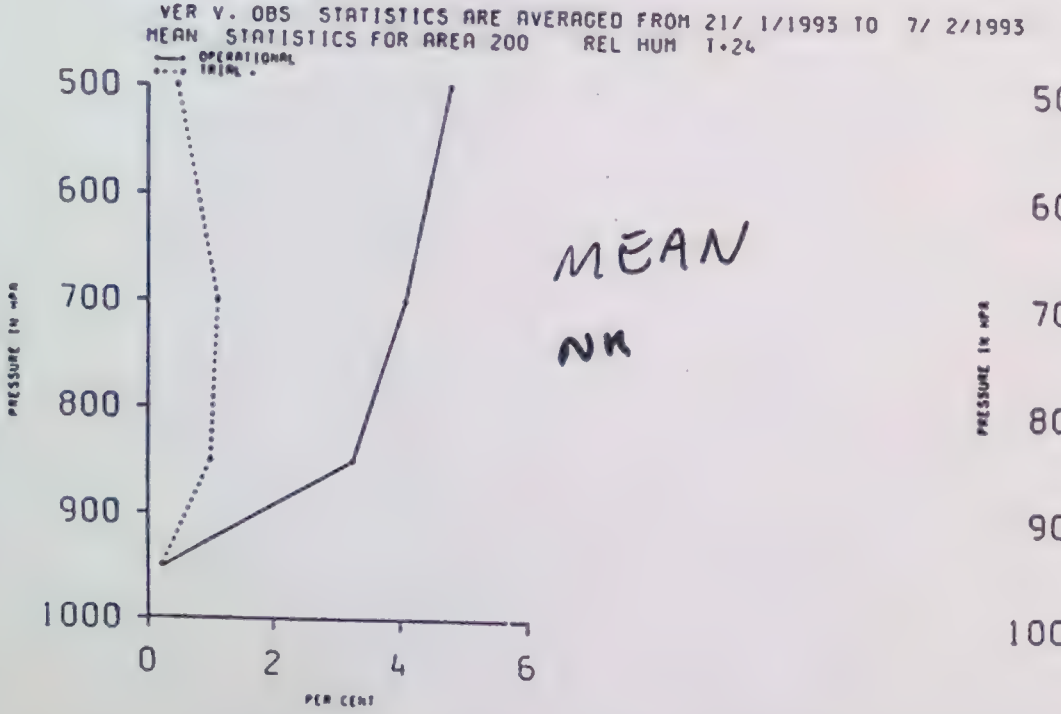
BIAS Relative Humidity T+24 RMS



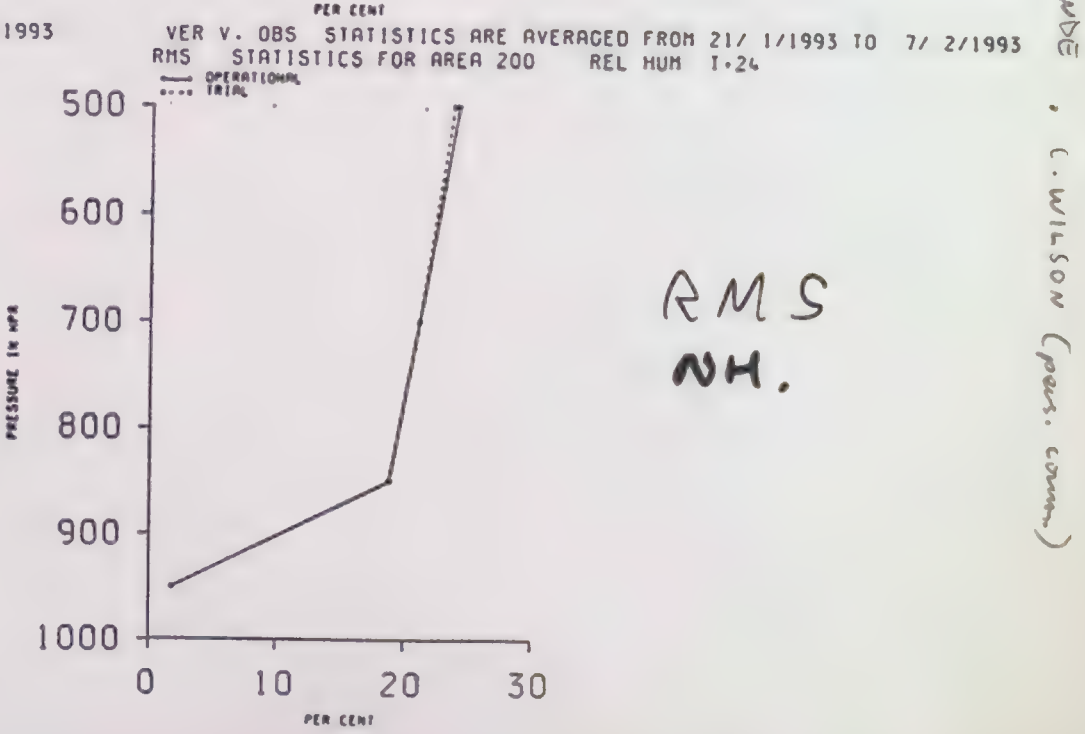
MEAN
N. Atlantic
%



RMS
N. Atlantic



MEAN
NH

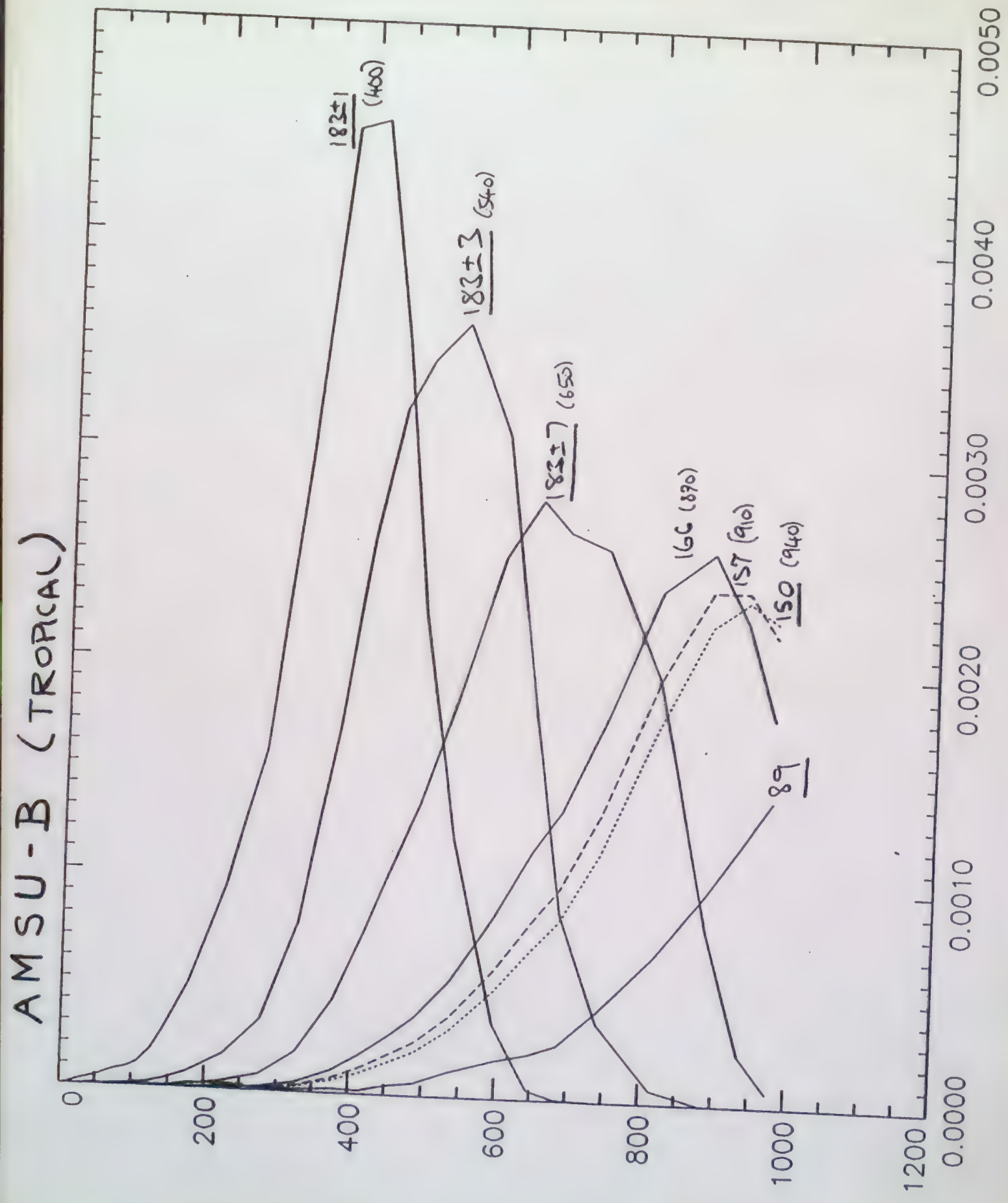


RMS
NH.

VERIFICATION : MODEL - RADIOSONDE . C. WILSON (pers. comm.)

FIG. 8

FIGURE 9

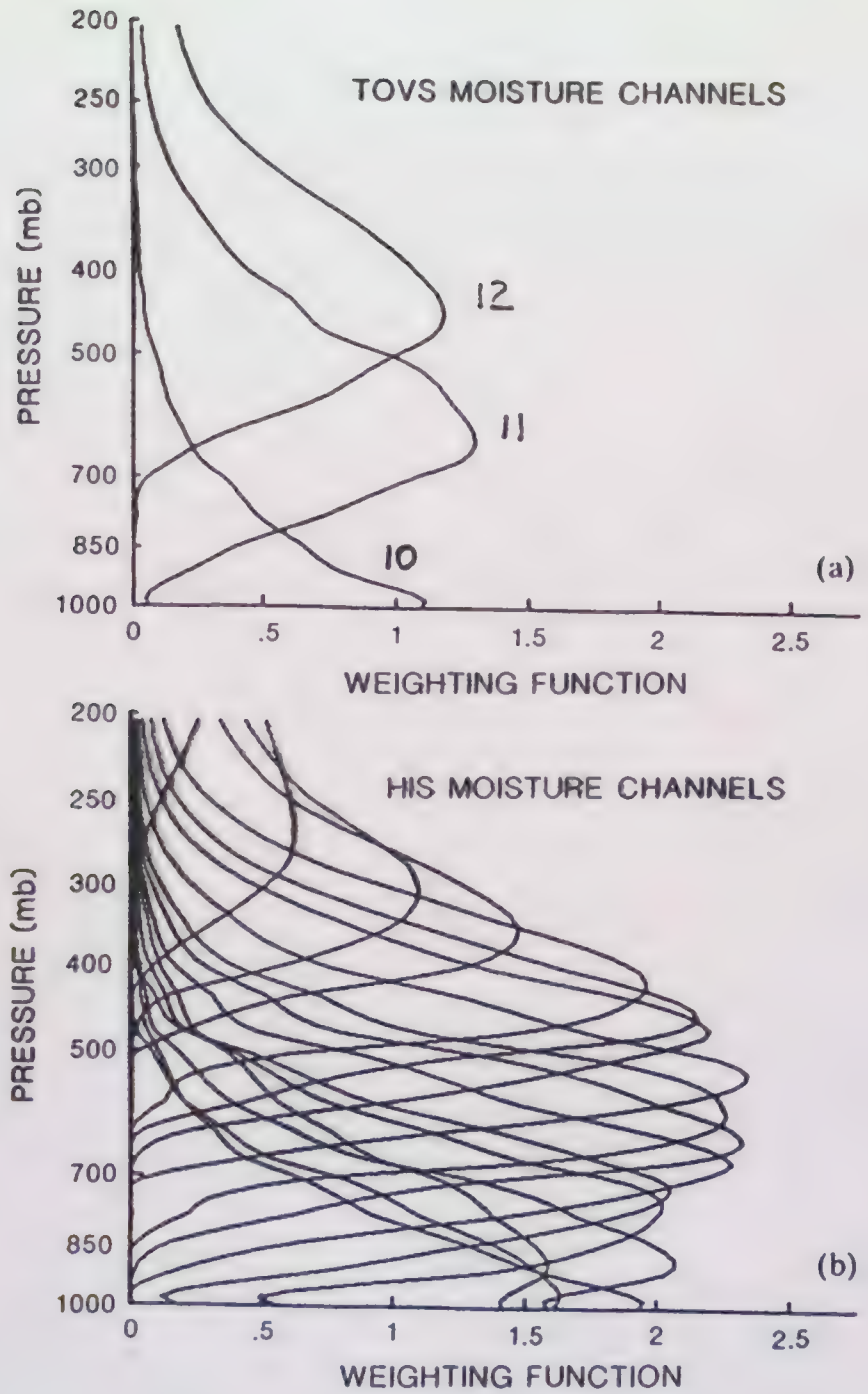


ATOVS/AMSU-B WEIGHTING FUNCTIONS

: WATER VAPOUR CHANNELS

FIGURE 10.

W. L. SMITH



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